

# Study on the spectrum of the injected relativistic protons

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**Abstract.** About 10 TeV  $\gamma$ -ray emission within 10 pc region from the Galactic Center had been reported by 4 independent groups. Considering that this TeV  $\gamma$ -ray emission is produced via a hadronic model, and the relativistic protons came from the tidal disruption of stars by massive black holes, we investigate the spectral nature of the injected relativistic protons required by the hadronic model. The calculation was carried on the tidal disruption of the different types of stars and the different propagation mechanisms of protons in the interstellar medium. Compared with the observation data from HESS, we find for the best fitting that the power-law index of the spectrum of the injected protons is about -1.9, when a red giant star is tidally disrupted, and the effective confinement of protons diffusion mechanism is adopted.

**Keywords.** stars: tidal disruption -black hole physics- galaxies: jets -Galaxy: center

## 1. Introduction

The central region of Milky Way is a potential site for the production of effective particle acceleration and copious  $\gamma$ -ray emission. TeV  $\gamma$ -ray emission from the Galactic Center (GC) had been reported by 4 independent groups in recent years: CANGAROO (Tsuchiya *et al.* (2004)), Whipple (Kosack *et al.* (2004)), HESS (Aharonian *et al.* (2004)), and MAGIC (Albert *et al.* (2006)). One possibility for this TeV  $\gamma$ -ray emission source is in the whole diffuse 10 pc region, which is proposed to be related to the massive black hole Sgr A\* harbored in our Galactic Center (Aharonian, Neronov (2005)).

There are several radiation mechanisms for the production of TeV  $\gamma$ -ray emission. One of these mechanisms proposed that the TeV  $\gamma$ -rays can be produced indirectly through the processes of  $\pi^0$ -decay when relativistic protons are injected into and interact with the interstellar medium (ISM), called hadronic model (Aharonian, Neronov (2005)). If this is the case, by assuming that the initial injected protons' spectrum follows a power-law plus a high energy cut-off, we can predict the spectrum of the injected relativistic protons by comparing the spectral energy distribution (SED) of the TeV  $\gamma$ -ray emission produced by hadronic model with observation data from HESS.

## 2. Model for the spectrum of the injected relativistic protons

To calculate the spectrum of the injected relativistic protons, we consider that the TeV  $\gamma$ -ray detected by HESS is produced through the hadronic model, and the injection of the relativistic protons required by the hadronic model came from the jet of the black hole Sgr A\* when it captures and tidally disrupts a star (Lu, Cheng & Huang (2006)).

The tidal disruption of stars by massive black hole Sgr A\* refers to main sequence (MS) stars and red giants. For these two cases, the total energy carried by the jet is exactly the same as  $2.7 \times 10^{51}$  erg, which is believed to be enough for the production of the injected

relativistic protons required by the hadronic model. The definite difference resulting from the two cases are the diffusion timescale of the injected protons: 800 yr for the case of MSs and  $2.11 \times 10^4$  yr for the red giants, respectively (Lu, Cheng & Huang (2006)).

Three kinds of diffusion mechanisms are involved for the propagation of the relativistic protons when they are injected into and interact with the ISM : (1) the Effective Confinement of Protons (ECP), (2) the Kolmogorov-Type Turbulence (KTT), (3) the Bohm Diffusion (BD). For these three mechanisms, the diffusion coefficient depends on the proton energy, given by the formula of  $D(E)=10^{28}(E/1\text{GeV})^\delta \kappa \text{ cm}^2\text{s}^{-1}$ . The case of ECP corresponds to  $\delta=0.5$  and  $\kappa=10^{-4}$ , KTT corresponds to  $\delta=0.3$  and  $\kappa=0.15$ , and BD corresponds to  $\delta=1.0$  and  $\kappa=10^{-2}$ .

Giving the initial injected relativistic protons spectrum follows a power-law plus a high energy cut-off, at a given time of  $t$  and the source distance of  $R$ , the SED of the TeV  $\gamma$ -ray emission produced through the model discussed above can be calculated through  $E_\gamma f(E_\gamma)=E_\gamma^2 V q_\gamma(E_\gamma, R, t)/S$ , where  $E_\gamma$  is the energy of the emitted  $\gamma$ -ray photons,  $V$  is the total volume of the ISM,  $q_\gamma$  is the emissivity of  $\gamma$ -ray photons, and  $S=4\pi(d_{ob})^2$ , where  $d_{ob}$  is the distance from the observation to the source, and we adopt  $d_{ob}=8\text{kpc}$  hereafter.

We address the SED of the emitted  $\gamma$ -rays in the following cases: (1) the different power-law index  $p$  of injected protons with values of 1.7, 1.8, 1.9, 2.0, 2.1, 2.2; (2) the MSs and red giants are tidally disrupted by massive black hole Sgr  $A^*$ ; (3) three diffusion mechanisms for the cases of ECP, KTT, and BD. By comparing the theoretical spectrum with the observation data from HESS within the central 10pc of our Galaxy, we find that the theoretical energy distribution can fit best with the observation data when the type of star disrupted by black hole is a red giant and the diffusion mechanism of protons is the Effective Confinement of Protons (ECP). In such a case, we derived that the power-law index of the injected relativistic protons is -1.9.

### 3. Conclusions and discussion

We have investigated the spectrum of the injected relativistic protons required by the hadronic model to produce the 10 TeV  $\gamma$ -ray emission detected by HESS in the center of our Galaxy. Comparing with the observations, we find that the power-law index of the initial spectrum of the injected protons should be -1.9. This result is based on that the tidal disruption of a red giant by the black hole Sgr  $A^*$  is considered and the propagation of protons in the target gas is the ECP scenario.

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